



# AN INTERACTIVE HAZOP TEACHING MODULE FOR ENGINEERING AND SCIENCE STUDENTS

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## ABSTRACT

An animated student-based teaching module for teaching the process safety technique HAZOP has been developed and is presented in this paper. The interactive software is designed to make the learning process more enjoyable and effective. The animated teaching module is available free of charge to potential users at the following website <http://www.cbme.ust.hk/haazop/4round/>.

**KEYWORDS:** hazard and operability study; guide-words; health safety environment (HSE); risk probability and prioritization; interactive online module;

## 1. Introduction

The educational requirements for engineering students have witnessed a steady change in emphasis from specific discipline training to interdisciplinary awareness and skills incorporating a wider range of information. An important development in this broader based curriculum is the growing emphasis on providing interesting and stimulating instruction modules, in particular, in areas associated with safety, environment and sustainability (Kletz, 1988). The changing emphasis is reflected in the professional competencies required by modern accreditation systems. As stated in ABET's Engineering Criteria (ABET, 2012), an important program outcome is for graduates to have "the ability to design a system, component, or process to meet desired needs within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability".

Students are often provided with a capstone design project near the end of their graduate studies and incorporate several of these features, but while "health and safety" is considered crucial by practicing engineers, it is often not addressed adequately in a curriculum. This could be due to the significant quantities of materials required for safety teaching (Wells, 1996; Center for Chemical Process Safety (CCPS), 2008; Rossing et al., 2010), or, the significant amounts of legislation, guidelines and codes of practice (Venkatasubramanian, Zhao and Viswanathan, 2000; Dunj6 et al., 2010; Rahman et al., 2009). There is often a lack of practicing expertise by teaching faculty and as such, it is generally considered a difficult area in which to stimulate students' appreciation and interest.

There are tens of widely recognized and used safety/hazard identification techniques (Montague, 1990; F. I. Khan and Abbasi, 1998; Tixier et al., 2002). Some of the more prominent identification techniques include: Safety Reviews, Index Methods (such as the Dow Fire and Explosion Index and the Mond-Dow Toxicity Index), What If Analysis, Preliminary Hazard Identification, Failure Mode and Effect Analysis FMEA, Hazard and Operability Study HAZOP, Hazard Analysis HAZAN, Event Tree Analysis, Fault Tree Analysis, Human Reliability and Cause Consequence Analysis. Several of these risk analysis methods are also used for identifying and assessing environmental impacts.

The subject of process safety is an essential area for practicing engineers and scientists. In recent decades, the world has witnessed numerous major accidents resulting in multiple deaths, millions of dollars of property damage, and major damage to our environment. Some examples include Bhopal (India) in 1984; Pemex LPG Center (Mexico City) in 1984, Exxon Valdez (Alaska) in 1989; and BP/Deepwater Horizon Spill (Gulf of Mexico) in 2010 (Toghiani and Elmore, 2011; Kahn, 2007; Laguna, 2010).

The term HAZOP is derived from HAZard and OPERability. Each safety technique has its own role to play, depending on the type of project, the type of industry, the phase of the project, the expertise of the safety team and others. The HAZOP study is of special interest to the process industries because it can be applied to both safety hazard identification and to identify environmental impacts. Perhaps the most significant reason for selecting the HAZOP technique to develop a special interactive teaching module for process engineers is because the HAZOP Study process has become a particularly popular safety hazard identification/analysis method for new process engineering projects, process revamps and major process modifications. It is usually the last hazard identification applied to the final stage P&IDs (piping and instrumentation diagrams), that

is 'the P&IDs issued prior to construction'. This key application represents the last opportunity to perform 'soft' changes to the process plant design. The HAZOP method is the most suitable method for this application because of its detailed nature, its structured and systematic methodology and the application of process guidewords to identify potential process deviations. In addition, the HAZOP process is constantly under review for possible improvement (Kletz, 1999, 1997; Swann and Preston, 1995; Kletz, 2010).

This paper describes the development of a comprehensive HAZOP teaching module. The first part of the module provides the students with course lecture materials and other skills which are summarized in section 2. Section 3 of this paper explains how the HAZOP modules were developed. Section 4 describes the interactive software module and how it is structured to enhance the students' learning and understanding. The overall HAZOP teaching module is evaluated in section 5.

## 2. Development of course materials

A set of course materials was developed initially to introduce the students to the HAZOP methodology. This lecture module was developed by asking and answering a series of questions. The next sections provide a flavor of the type of materials covered in the lecture module.

### 2.1 What is a HAZOP?

A hazard and operability study (or HAZOP) is a systematic, critical examination by a team of the engineers and operators of a process to assess the hazard potential of mal-operation or mal-function of individual items of the process and the consequential effects on the facility as a whole.

HAZOPS are meetings with a distinct structure; the structure imposing a certain organization to enhance effectiveness. They are a generalized study technique, equally applicable to microchip manufacture, oil refining, petrochemicals, food and drink, pharmaceutical synthesis, plastics and polymer plants, effluent plant operation, water treatment or any other process industry.

They should not be seen, however, as a solution to all ills. The HAZOP procedure is only another tool in the safety locker and should be seen as complementary to other techniques.

### 2.2 Why is a HAZOP carried out?

The reasons for carrying out hazard and operability studies are:

- i. Primarily, to identify hazards, and
- ii. To a lesser extent, to resolve these hazards.

In saying this, hazards are very generally defined. They are understood to be events, which:

- i. Lead to injury of people, either inside or outside the plant.
- ii. Damage the environment.
- iii. Insult the environment. Harmful effects may not occur, but disturbance itself is unacceptable.
- iv. Damage the plant, an obvious hazard.
- v. Result in loss of production quantity, quality or schedule.

### 2.3 When is a HAZOP carried out?

The timing of a hazard and operability study is determined by the objectives of the study, and in turn determines the benefits that may be gained. The outline concept of a process may be examined to highlight any major omissions or significant features. As further design detailing is carried out, e.g. when the detailed process design is complete with PFDs and P&IDs, the full study procedure may best be applied. Operating procedures may be examined to ensure that all eventualities have been considered.

Modifications including so-called “minor modifications”, generally benefit from a rigorous study. Often an apparently simple, uncomplicated modification can give rise to a greater problem than it was intended to solve. Consider the nuclear power plant at Chernobyl in Russia, when during the shutting down of the nuclear reactor in 1986 it was decided to carry out an energy recovery study to assess if more heat could be utilized during the shutdown procedure. Too many control rods were removed and a runaway reaction proceeded resulting in a series of explosions and fires and a major release of radioactive fission materials (Bell and Shaw, 2005).

Testing procedures and protocols also need to undergo a HAZOP study to ensure that systems, not normally operational, such as safety critical systems, will work when an emergency arises. For example, the major accidents at Seveso (Bertazzi, 1991) and Bhopal (Ayres and Rohatgi, 1987; Chouhan, 2005).

Maintenance operations should also be included in HAZOP safety studies since major accidents have occurred during such operations; for example, Flixborough, UK (Venart, 2004) and Sterlington, USA (Mihailidou, Antoniadis and Assael, 2012).

Existing plant and new equipment are other examples of topics that may benefit from a HAZOP study. Therefore, a project may be studied several times in its life-time.

### 2.4 What is the HAZOP study procedure?

The blocks in Figure 1 outline the whole HAZOP procedure. Block 9 represents the actual HAZOP Study meeting. The HAZOP takes 1.5-3 hours per main plant item (still, furnace, reactor, heater, etc.). If the plant is similar to an existing one, it will take 1.5-2 hours per item; but if the process is new, it may take more. To give the team time to attend to their other duties, meetings are usually restricted to 3 hours, twice per day, 2-4 days per week.

The HAZOP on a large project may take several months, with 2 or 3 teams working in parallel on different sections of the plant. It is thus necessary to either:

- Delay detailed design and construction until the HAZOP is complete, or
- Allow detailed design and construction to go ahead with the risk of having to modify and/or alter the detailed design or even the plant when the results of the HAZOP are known.

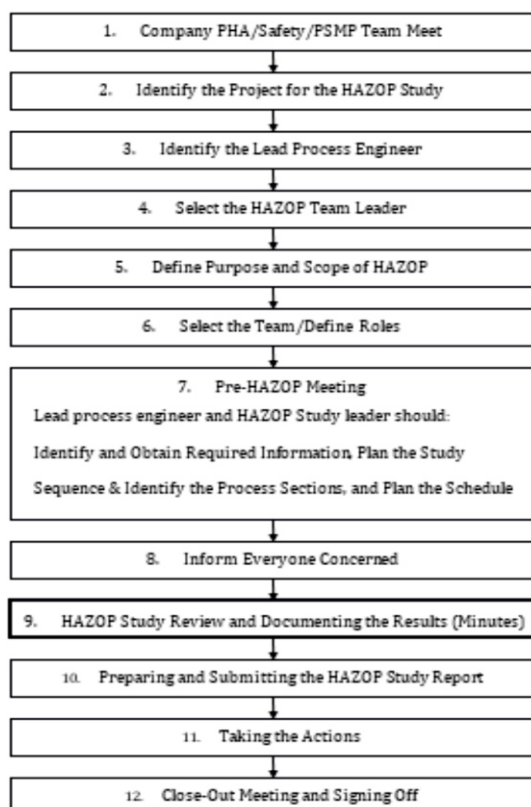


Figure 1: Overall procedural steps in a HAZOP Study

Ideally, the design should be planned to allow time for a HAZOP study before detailed designs and construction begin.

An interdisciplinary team comprising of engineers, chemists, project managers, process operators, maintenance staff, services engineers, contractors, equipment suppliers, etc., are required to attend the HAZOP Study Meeting. All relevant team members must attend, as the success of a HAZOP Study depends on the professional expertise and ability to answer all questions raised in an effective manner.

The HAZOP study then examines each Process Drawing in turn, by dividing the process drawing into 3 or 4 process section (or study nodes). Each process section is then examined for deviations that could occur leading to process upsets. The examination is carried out in a logical structured manner for each process section using a series of guidewords.

### 2.5 What are Guidewords?

Guide words are simply words used as keys to suggest the various ways in which deviations from an intention can occur. A list of guidewords and their meanings is provided in Table 1. Firstly, the intention can fail completely and nothing at all happens. This is prompted by the ‘NO’ or ‘NOT’ guideword. For example, a ‘no flow’ situation can exist if a pump fails to start. If there is a quantitative variation, it may be described by ‘MORE’ or ‘LESS’. This refers to quantities, physical properties and activities. For example, more reactant than is required, a high mole ratio in a reactor, less reaction, and so forth.

Table 1: A List of HAZOP guidewords

GUIDE WORDS	Explanation
NONE	No forward flow when there should be, i.e. no flow or reverse flow.
MORE OF	More of any relevant physical property than there should be, e.g. higher flow (rate or total quantity), higher temperature, higher pressure, higher viscosity, etc.
LESS OF	Less of any relevant physical property than there should be, e.g. lower flow (rate or total quantity), lower temperature, lower pressure, etc.
PART OF	Composition of system different from what it should be, e.g. change in ratio of components, component missing, etc.
AS WELL AS / MORE THAN	More components present in the system than there should be, e.g. extra phase present (vapour, solid), impurities (air, water, acids, corrosion products), etc.
REVERSE	A parameter occurs in the opposite direction to that for which it was intended e.g. reverse flow.
OTHER THAN	Complete substitution e.g. sulphuric acid was added instead of water.
EQUIPMENT WORDS / 'OTHER'	What else can happen apart from normal operation, e.g. start-up, shutdown, uprating, low rate running, alternative operation mode, failure of plant services, maintenance, catalyst change, etc.

The GUIDEWORDS are applied to a range of process PARAMETERS. Usually only a limited number of combinations of guidewords and process parameters are used. The most common process parameters are shown in Table 2 and the four in the first column (FLOW, PRESSURE, TEMPERATURE and LEVEL) are the ones most frequently used. Others will be tested and used on a case basis if required.

Table 2: A List of process parameter guidewords

Flow	Time	Relief	Utilities
Pressure	Composition	Viscosity	Other
Temperature	pH	Mixing	Separation
Level	Speed/Frequency	Addition	Reaction

Each guide word is combined with relevant process parameters and applied at each point (study node, process section, or operating step) in the process that is being examined. The word ‘other’ allows additional words to be added to the list as certain projects may want to emphasize particular areas of concern eg. containment, static fire risks, or sampling procedures. Table 3 gives an example of creating deviations using guide words and process parameters.

Table 3: Combining guide words and parameters to create deviations

Guide Words		Parameter		Deviation
NO	+	FLOW	=	NO FLOW
MORE	+	PRESSURE	=	HIGH PRESSURE
AS WELL AS	+	ONE PHASE	=	TWO PHASE

As an example, the use of the parameter FLOW with various guidewords of Table 1 can result in a variety of deviations such as: NO FLOW, MORE FLOW, LESS FLOW, or REVERSE FLOW. The list of guidewords used in the Animated HAZOP module developed in this study is from the Chemical Industries Association list.

Table 4 contains a more detailed list of guidewords and deviations with examples for each deviation of how this might occur. Table 4 is also shown in the software teaching module as an aid for the students.

**Table 4: Example applications of parameters, guidewords, and deviations**

PARAMETER	GUIDE WORD	DEVIATION	EXAMPLE
FLOW	NONE	No Flow	Wrong routing, complete blockage, slip plate, incorrectly fitted non return valves, burst pipe, large leak, equipment failure (control valve or isolation valve, or pump, vessel etc.)
	REVERSE	Reverse Flow	As above
	MORE OF	More Flow	More than one pump, reduced delivery head, increased suction pressure, static generation under high velocity, pump gland leaks.
	LESS OF	Less Flow	Line blockage, filter blockage, fouling in vessels, valves, etc. and restriction of orifice plates.
PRESSURE	MORE OF	More Pressure	Surge problems (line and flange sized) (leakage from any connected higher pressure system, thermal relief.
	LESS OF	Less Pressure	Generation of vacuum condition
TEMPERATURE	MORE OF	More Temperature	Higher than normal temperature, fouled cooler tubes, cooling water temp wrong, cooling water failure.
	LESS OF	Less Temperature	Line freezing.
VISCOSITY	MORE OF	More viscosity	Incorrect material specification, temperature, etc.
	LESS OF	Less viscosity	As above
COMPOSITION	PART OF	Composition Change	Passing isolation valves, double isolations.
	MORE THAN	Composition Change	More A added, More B added.
	OTHER THAN	(Contamination)	Wrong material, wrong operation, ingress of air, shutdown and start-up conditions.
OTHERS		Relief	Sizing for two phase
		Instrumentation	Control, flow measurement, pressure relief, instruments, pump overheating due to closed control valves, location of alarms, etc., temp. indicators, flow recorders, etc.
		Sampling	
		Corrosion	
		Service Failure	Cooling water, instrument air, steam, nitrogen, electrical power, etc.
		Maintenance	System drainage, isolation of equipment, preparation for maintenance, shutdown and start-up.
		Static	Plastic lines, solvent velocities, earthing
		Spare Equipment	Critical equipment
		Safety	Lagging, fire fighting, toxic gas, safety showers, security etc.

### 3.0 Study module development methodology

Before the development of the HAZOP module, students and faculty members were interviewed to discern the problems of the previous courses. The main criticisms of previous HAZOP training was as follows:

- To do a HAZOP, the students needed to utilize all the existing course materials they had studied previously –they found this difficult.
- Much of the existing theoretical part of the HAZOP lectures was a bit heavy and dry. The students listened to the lecturer telling them about how to apply a whole series of process GUIDEWARDS and what the consequences were.
- The results of the HAZOP study are primarily qualitative; the students did not have exact answers and were not too familiar with this type of assessment. In other words, there is often no absolutely correct answer to a HAZOP –there are a number of correct solutions as well as many incorrect ones.
- Due to the length of time involved in the HAZOP practical sessions performed during open ended Final Year Design Project classes, some students missed sessions because they had other commitments, job interviews, etc.
- Because the Design Project has 3 processes each year, with some processes changing every year, it is very difficult and time consuming for the faculty to develop all the alternative solutions.

To overcome these challenges, we decided to develop a new teaching module which at its core had an-animated HAZOP software kit using dynamic simulation and computer graphics to engage undergraduate students in a visual, sequential decision-making process. The main idea is to allow students to work in a multi-disciplinary team in a simulated work context. The project was carried out in three phases:

Phase 1 – Development of HAZOP Study Teaching Module (12 months)

Phase 2 – Extension of the HAZOP Study Teaching Module (9 months)

Phase 3 – Adaptation of the HAZOP Study Module to include New Case Studies (7 months)

The key objectives to be addressed and incorporated in the project were:

1. Role-play experience – Chairperson, Technical Secretary, etc.
2. Performing well in meetings and communications – two way, verbal, written
3. Working in a team
4. Multi-disciplinary activity
5. Working in a real world “Design Office” environment
6. Systematic thinking, problem solving skills and analysis
7. Very wide-ranging knowledge base applications
8. Evaluation and reflection assessments for the HAZOP Teaching Module

A plan of actions was developed in order to address how these teaching and learning issues would be incorporated into the teaching module. The following points were implemented in the module:

1. Guidelines on role tasks are included.
2. Team selection and good team characteristics are presented in the course module; including: ‘managing a team’, ‘selecting and shaping your team’, ‘barriers to effective teamwork’, ‘developing your team’, ‘supportive team practices’, ‘good communication and motivation’, ‘handling trouble’, and ‘when is a team really a team?’.
3. Participants from other subject disciplines are invited to HAZOP meetings to make them multi-disciplinary,
4. Time schedules and constraints are re-imposed to achieve targets and deadlines typical of design office pressure.
5. Examples are provided in the module to direct students to think independently, systematically, and to solve problems.
6. Development of a specialist animated graphics unit within the teaching module to provide case study examples. This integrated the many course facets the students need to apply to appreciate HAZOP Study Analysis.
7. Evaluation and reflection assessment processes were carried out by holding a series of meetings with students.



This teaching module was developed jointly by two teams from the Department of Chemical and Biomolecular Engineering (CBME) and Center for Enhanced Learning and Teaching (CELT, a central educational development unit). It was important that members of the two teams developed a detailed list of assigned tasks and a schedule at the project planning stage. This was carried out and the program of activities to deliver the full HAZOP module was established, with regular scheduled progress review meetings. A linear approach was introduced so that students were guided step by step. Different roles were introduced to let students have different learning experiences and development of their problem solving skills in a versatile learning environment. These activities enrich the old teaching method and benefit students.

#### 4. HAZOP interactive software module

The implementation methodology was carried out in three phases mentioned previously. Here, the results for each phase will be discussed in sequence. The class implementation was based on a two hour introduction to HAZOP through the course materials summarized in Section 2 of this paper. This was followed by a one and a half hour computer based interactive session using the animated HAZOP study module. The animated HAZOP study module can be accessed free of charge via: <http://www.cbme.ust.hk/haazop/4round/>

This first development phase focused on the content of the HAZOP module. What would make it different from a 'stand-up, front of class' delivery and what could be done to engage students to use the module? The module should include several prompts requiring the student to input and participate in a major way to complete the tasks. The CELT team was experienced in methods of identifying the strengths and problems of encouraging student active participation. After extensive discussion, it was decided to base the module design on: a "good guy" versus "bad guy concept" (Figures 2 and 3). The module would use a series of questions and answer prompts for the students to make a selection; the inclusion of some humorous elements would also stimulate the students' interest and enjoyment of the module.

The first stage of the Phase 1 module development was to produce a Piping and Instrumentation Diagram (P&ID) of a reasonably simple process requiring several actions for the students to practice and develop. The module begins with an Introduction outlining the structure of the module in seven sections as:

Section 1: Introduction

Section 2: Plant Diagram. This is shown in Figure 2 and a description of the process is provided.

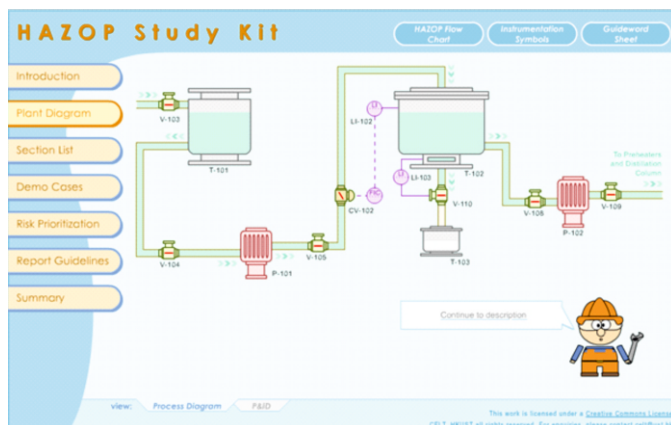
Section 3: Section List, showing the process sections or study nodes. The process sections are also shown in Figure 2.

Section 4: Demo Cases. Five demonstration cases were developed in Phase 1 and then a sixth case was added as part of Phase 3.

Section 5: Report Guidelines. The software package generates its own HAZOP Study Minutes Report as the students work their way through the module.

Section 6: Risk Prioritization. A risk prioritization analysis package was added in Phase 2 of the teaching module development.

Section 7: Summary



In brief, the process involves a wet hydrocarbon mixture being fed to a storage tank T-101 and from there the wet hydrocarbon feed is pumped via pump P-101 to a buffer storage tank T-102, where the liquid feed is given sufficient buffer time to separate out most of the water which falls into the catch tank T-103. The dried hydrocarbon feed mixture can then be pumped from T-102 through heat

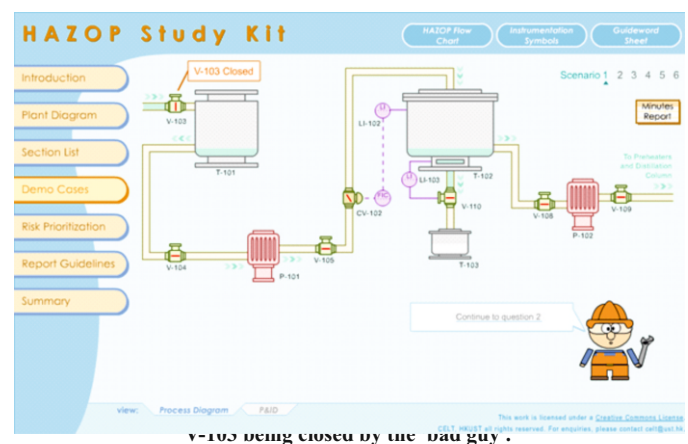
exchangers to the distillation column for separation. The heat exchangers and distillation column are not shown on the process drawing.

In addition to the process schematic, Figure 2 shows the process sections or study nodes and the student is guided to his HAZOP study task which is process section/study node 3. This includes the wet hydrocarbon feed line from T-101 through to the buffer tank T-102 and includes the buffer tank T-102 and the water catch tank T-103.

In addition, a number of links providing guidelines and support information to assist the students' progress were developed in the module, including:

- (i) HAZOP Flow Chart
- (ii) Instrument Symbols
- (iii) Guidewords Sheets – with the provision of technical assistance on the application of the guidewords shown in Table 4
- (iv) Access to follow the development of self-generating PFDs
- (v) Access to follow the development of self-generating P&IDs
- (vi) Access to follow the development of a self-generating Minutes Report
- (vii) Risk Hazard Severity Guideline table (Phase 2)
- (viii) Risk Probability/Frequency Guideline table (Phase 2)
- (ix) Risk Prioritization Guideline table (Phase 2)
- (x) Access to follow the development of a self-generating HAZOP Prioritization Report (Phase 2).

Next, the module takes the students into the demo case studies. In the first step, the module initiates the student to propose the scenarios for NO FLOW and introduces scenario 1. The prompt given to the student is valve V-103 is closed and the student has to provide a correct input from a series of prompts – the whole process system to the right of V-103 will run dry and the process will stop. Now the software shows our 'bad guy' comes along and closes valve V-103 on storage tank T-101, so that the downstream lines and vessels run dry. This is shown in Figure 3.



The students are then asked "what is the consequence, will the operators know quickly that something is wrong, what can be done?"

The students submit their answer and the module prompts the correct answer.

The module then requests a solution and suggests, "We'd better install a Level Indicator (LI)." The good guy then gives the students a choice between a High Level Indicator and a Low Level Indicator. After the student inputs the Low Level Indicator correctly, the module gives another prompt "is this sufficient" and asks the student to select from the options shown in Figure 4.

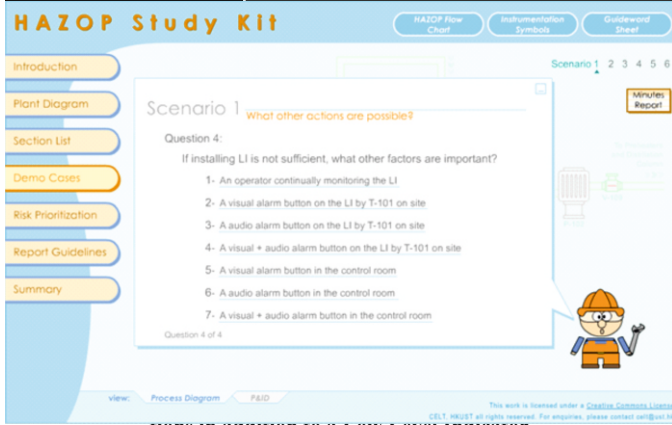


Figure 5: HAZOP Study Kit interface showing Scenario 1.

After selecting the best input, the 'good guy' proceeds to make the instructed adjustments and installations.

Highlights from the other case studies will be quickly reviewed in this paper. For a full understanding of the module details, readers are encouraged to access the module online.

Scenario 2 regards the possibility of CV-102 failing to close. In order for students to understand the consequences of such a failure, the 'bad guy' comes and closes CV-102. The module provides the following explanation to students:

"CV-102 Closed → T-102 Runs Dry → No Flow to Distillation Unit → Process Stops"

The students see that the fluid in the buffer tank and in the pipelines empty and run dry after CV-102 is closed. Using a prompt box it is asked: "How can we fix the process system when CV-102 is closed?"

This case study prompts team discussion on more than one option available. After the student inputs a solution, followed by clicking, the answer comes up: "Install a manual valve, V-107, in parallel which can be opened enabling the fluid to by-pass the control valve CV-102, for a short time in the event of an emergency." Our 'good guy' then appears and makes the modification and the animated flows start again. The automatically generated HAZOP and P&ID are shown to the students.

But the students should also consider the possibility of a duplicate control valve, CV-102B, and the implications of the large price difference versus the damage or cost of loss in production if a manual by-pass valve is installed. This discussion should include where the Level Indicator should be located to give sufficient buffer time for a maintenance check to see if a fast repair is possible or sufficient buffer capacity to shut down the distillation process. The quality of the existing control valve must be checked, regularly inspected and provided with an in-line calibration facility.

The third Scenario concerns the closure of valve V-105. After asking for suggestions from the students, the module explains that under such a condition, P-101 will deadhead against the valve. Again, the 'bad guy' comes and closes the valve and the software shows the potentially more serious impacts of this scenario in Figure 5. So the students discussion here should include the value of the dead head pressure versus the line design pressure, the liquid inside the impeller casing heating up to boiling and causing cavitation, provision of kick-back line and relief valve.

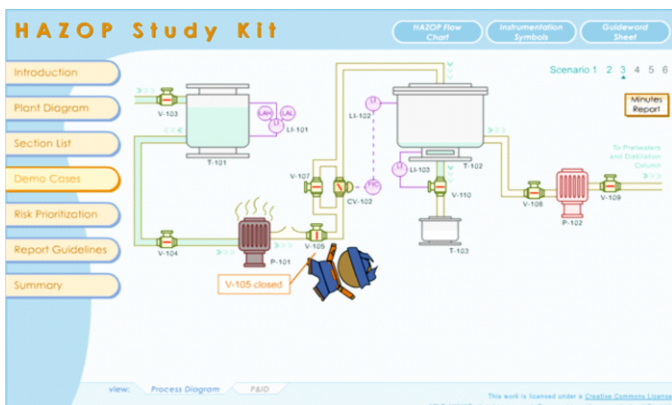


Figure 6: HAZOP Study Kit interface showing Scenario 1.

The fourth scenario prompt for NO FLOW is: "Failure of Pump P-101". The students are prompted to find a solution such as a providing a kick-back line and/or

pressure transducer. After the students are informed of the benefits of the possible options, the 'good guy' in our module installs the associated lines and instrumentation. The animated schematic is shown in Figure 6.

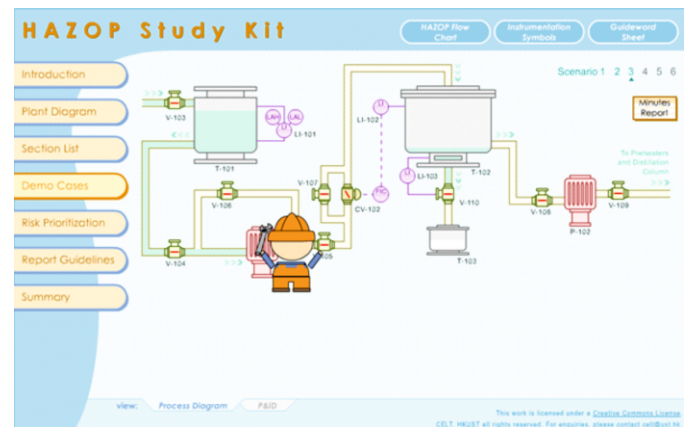


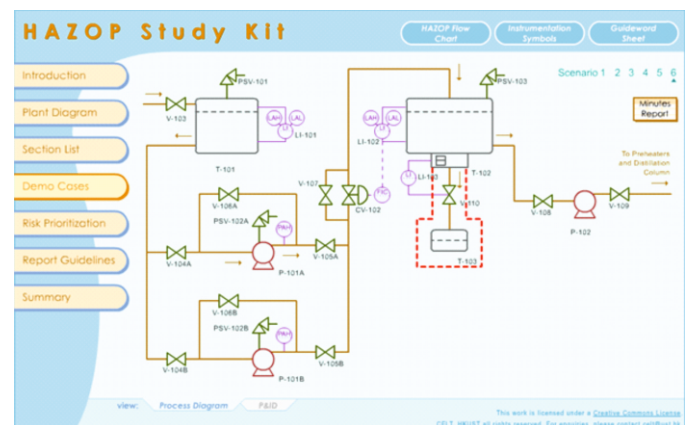
Figure 7: HAZOP Study Kit interface showing Scenario 1.

Scenarios 4-6 are not discussed in this paper.

As mentioned earlier, the software generates its own HAZOP Study Minutes Report as the students work their way through the module. In addition to solving the case study scenarios, the software teaching module has the facility to continually generate the HAZOP Study Minutes Report after each scenario has been developed. Figure 7 shows the update HAZOP Minutes after scenario 3.

Figure 8: HAZOP Study Kit interface showing Scenario 1.

For every scenario there is a prompt at the bottom of the screen "P&ID" enabling the student to see the P&ID form of the schematic. Figure 8 shows the status of the P&ID after all the scenarios (including installing a standby pump, insulated heating tape, and other instrumentation) have been implemented.



At the end of 12 months when Phase 1 was completed a number of extensive surveys were carried out and feedback was obtained from student users and at peer level from teachers and industrialists. The results of the evaluations feedback resulted in our proposal for an extension award of the original project to incorporate a methodology for prioritizing the HAZOP Actions. In addition, there was



considerable support in the industrial feedback to develop a Hazard Prioritization methodology into the teaching module emphasizing the importance of this route in process hazard analysis and environmental analysis. We obtained a further 6 month funding to develop and incorporate a Prioritization Method into the module for the students to prioritize the HAZOP Actions (Vaidhyanathan and Venkatasubramanian, 1996; Casamirra et al., 2009; Hyatt, 2011; Bris et al., 2014; Kotek and Tabas, 2012; Mortazavi et al., 2011).

As shown in Figure 9, a table was developed in the software for the Hazard Severity rating, H, dividing the severity into 5 category levels on a numerical scale.

**HAZOP Study Kit**

HAZOP Flow Chart | Instrumentation Symbols | Guideword Sheet

Introduction | Plant Diagram | Section List | Demo Cases | Risk Prioritization | Report Guidelines | Summary

Degree of Safety	Description	Hazard Severity Rating
Safe	The component or equipment cannot fail or it will fail safe and not cause a hazardous situation or operability problem.	0
Minor Hazard	The component or equipment failure, it will fail safe (cannot cause a hazardous situation). Maximum damage will be less than HK\$1,000,000. Minor operability problem.	1
Marginal	The incident results in a medium operability problem or minor injuries to employees.	2
Unsafe	The incident could cause a single serious injury and/or property/business loss less than HK\$1,000,000. Major operability problem.	3
Very Unsafe	The incident will probably cause major (HK\$1,000,000-20,000,000) and/or personal injury, possibly a single fatality.	4
Extremely Unsafe	The incident will probably cause multiple failures in the process; the failures would cause serious personal injury and multiple fatalities and/or property/business loss consequences of HK\$ 20,000,000 or more, offsite exposure, or environmental damage.	5

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numerical values.

Students must now analyze the actions and consequences in more detail in order to assign a rating to each of them. The module uses the Risk Rating, R, based on the following equation:

$$R = H \times P$$

where F is the frequency or probability of the deviation and hence the actual event occurring. Since this level of information is outside the usual realm of student knowledge base, we provide strong indicators within the frequency prompt sectors to target the probability for each action item. The probability rating scale is shown in Figure 10.

**HAZOP Study Kit**

HAZOP Flow Chart | Instrumentation Symbols | Guideword Sheet

Introduction | Plant Diagram | Section List | Demo Cases | Risk Prioritization | Report Guidelines | Summary

Description	Failure Frequency (Probability)	Rating (P)
Highly Likely	1 or > in a yr	5
Very Likely	1 in 2-5 yrs	4
Likely	1 in 6-15 yrs	3
Remote	1 in 16-35 yrs	2
Very Unlikely	1 in 35 yrs or >	1

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numerical values.

This Risk Rating scale gives 15 possible values and as such is more sensitive than the additive numerical scale which yields only 10 values. However, where the risk score is composed of two diverse values of H and F, the final score may underestimate the importance of a risk. For example a score of 10 implies: H = 5 or 2; and F = 2 or 5.

Another example is 5, which implies: H = 5 or 1; and F = 1 or 5.

In both cases, when H = 5, it may be advisable to move this risk item into the next higher category.

Generally as the risk rating decreases, so does the priority of the hazard. Hazards with a Risk Rating of 25 and 20 (4×5, or, 5×4) are characterized as class 1 risks which are essential to be dealt with. A Risk Rating of 16, 15, or 12 characterizes a class 2 hazard, followed by class 3 hazards with Risk Ratings of 10, 9, 8, or 6. Risk Ratings of 2-5 signify a class 4 hazard, followed by a (low) class 5 hazard with a Risk Rating of 1 (1×1).

With the help of the software's guidelines, the module assists students in preparing a risk prioritization table as seen in Figure 11.

**HAZOP Study Kit**

HAZOP Flow Chart | Instrumentation Symbols | Guideword Sheet

Introduction | Plant Diagram | Section List | Demo Cases | Risk Prioritization | Report Guidelines | Summary

No.	Guideword	Deviation	Possible Causes	Possible Consequences	Hazard Severity (H)	Probability Frequency (P)	Criticality Risk (R)	Safety Classification
1.1	FLOW	NO FLOW	Valve V-103 Closed	a) Tanks T-101 and T-102 Run Dry	5	1	5	

Case Study: Determination of Hazard Severity Rating (H)

Select a Hazard Severity Rating (H) value. You may check the Hazard Priority Table for guidelines.

Review the Schematic.

HAZOP Priority Table  
 Frequency Priority Table  
 Risk Priority Table

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Figure 11: Generation of a risk prioritization table with the aid of the HAZOP software.

## 5. Evaluation process

During the project, several reviews/surveys were carried out to monitor the development and the effectiveness of the module. The procedures for reviewing were similar for each of the three phases of this project, namely:

1. Progress review meetings/reports
2. Collect data to assess the effectiveness of planned actions and outcomes
3. Close out interviews

CELT led the development of a range of comprehensive survey/questionnaire forms to assess the effectiveness of many aspects of the project, over a three year period including:

1. Department of Chemical Engineering, HKUST
2. Survey questionnaire for students to complete (4 universities)
3. Survey questionnaire for industrialists to complete (6 industrialists)
4. Survey questionnaire for peers to complete (6 faculty)
5. Feedback from HKIE Professional Accreditation

Several of the key comments which led to various types of improvement included:

- visualization and color
- user friendliness
- making the program go back as well as forward
- provide easier access to prompts
- accessing data sources
- more apparent labeling
- comprehension
- technical feedback
- more model scenarios
- no quantitative data provided, could something be included

These points led to the implementation of Phase 2, to develop the Prioritization Ranking Methodology, and Phase 3 of the project, to add two more case study scenarios and make them different from NO FLOW.

## 6. Conclusions

An animated software has been developed for teaching the process safety technique HAZOP to undergraduate students. The interactive module is designed to make the learning process more enjoyable, while providing an effective method for students' skill enhancement. At the end of Phase 1, the project outcomes were very satisfactory. Students' feedback was received in an excellent manner and provided a driving force for extending the projects with more case study scenarios. At the beginning of the project, though some project management issues were aroused, they were sorted out very soon because of the close cooperation between the teaching team and CELT. This good relationship led to a very smooth development for Phase 2 and Phase 3. A triangulation of evaluation results (both quantitative and qualitative) from students, and academic and industrial peers showed that the teaching module has accomplished its key objectives. The animated teaching module is available for use at <http://www.cbme.ust.hk/hazop/4round/>

Feedback and comments regarding the module can be sent to the corresponding author of this paper at kemckayg@ust.hk

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